

proportion. And the ultimate result may be that for practical purposes the limiting range is raised on account of the great length of time required to cause fracture. Further, it is noted that when the rate of fatigue is very slow the property of recovery becomes relatively more important, and it is at least conceivable that it may be more than competent to overcome the fatigue altogether and so really raise the limiting range.

The observations described in this paper were for the most part taken and reduced by my assistant, Mr. H. Quinney, whom I must thank for the zeal and ability with which he has carried out the work. I wish also to acknowledge valuable assistance given at various stages by Mr. C. Trevor-Williams, advanced student in the University of Cambridge, and by my brother, Mr. R. C. Hopkinson, Trinity College.

*The Mechanism of the Semi-permeable Membrane, and a New
Method of Determining Osmotic Pressure.*

By Prof. F. T. TROUTON, F.R.S.

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Introduction.

For the theoretic exposition of osmotic pressure, no further attention need be paid to the membrane than to postulate its semi-permeability. It is, however, desirable that the physical properties of the membrane should not be lost sight of, especially from the experimental point of view.

Leaving out of account for the moment the mechanical requirements of a rigid membrane, let us imagine a system in which we have a solution separated from the pure solvent by a thick layer of another liquid which can take up or dissolve the solvent, but not the solute.

Such a system might be sufficiently realised by means of an aqueous solution of cane sugar, ether, and water, since sugar is insoluble in ether, while ether dissolves a small quantity of water. Both water and sugar solution take up some ether, but that is of no immediate interest in the present considerations. This complication will be, however, dealt with later on. If it is desired to imagine the necessities of gravity complied with, the sugar solution and the water can be supposed to be placed side by side in a vessel and kept from mixing by an impervious vertical partition reaching to

a certain height ; then ether poured in, so as to cover all and to act the part of a semi-permeable membrane separating the solution from the water.

Ether takes up about 1.05 per cent. of water when placed in contact with it, but takes up less than this from sugar solution, the amount depending upon the concentration of the solution. For equilibrium at the water-ether surface the ether must thus contain 1.05 per cent. of water, while at the solution-ether surface a less quantity is necessary for equilibrium to exist there. Diffusion through the ether prevents this equilibrium existing, so that water will pass across from the water side to the solution side.*

If the ether could rigidly maintain its position so as to prevent the volume of the solution increasing, the hydrostatic pressure of the solution would go up owing to water passing into it. This process, we must suppose, would, under such circumstances, come to an end when, owing to the increase of pressure, the amount of water taken up by the ether from the sugar solution reached the amount taken up from water at the ordinary pressure.

A practical equivalent to the assumed rigidity might be provided in our supposed experiment by having the level on the solution side lower than on the water side, the difference in levels depending upon the strength of the solution used. By making the column of ether sufficiently high, the necessary pressure could obviously always be provided to enable the amount of water held by the ether at the solution-ether surface to equal that held near the water-ether surface.

The pressure competent to bring about this state of equilibrium in the ether would thus appear, from the above considerations, to be the osmotic pressure of the sugar solution.

The complication above alluded to, arising from the solution of our "membrane" in both the solution and solvent, introduces probably only an apparent and not a real difficulty, and is met, it would seem, in the case of sugar solution, ether, and water, by the amount of ether held by the solution when under the equilibrium or osmotic pressure being equal in amount to that held by water at the normal pressure. It is well known that the presence of a salt in water causes a reduction in the amount of ether taken up when ether is placed in contact with the solution, but this amount rises with the pressure. No accurate quantitative determinations have been obtained as to the amount of this, but some qualitative observations bear out the above assumption, in which case the solvent would simply be a solution of ether-water instead of pure water.

We could under these circumstances infer that in order to determine the

* A small correction may be required to allow for the equilibrium distribution of concentration depending upon the gradient of pressure in the ether.

osmotic pressure of a given solution it is only necessary to find the pressure to which a suitable liquid, say ether, must be subjected when in contact with the solution, in order that the liquid may take up as much water from the solution as the liquid takes up from water at the ordinary pressure.

Method of Experiment.

In order to determine osmotic pressures on this principle an apparatus was constructed in which the solution in contact with ether, or other suitable liquid, could be subjected to hydrostatic pressure of any desired amount. It consisted of a copper U-tube strong enough to stand high pressures, and closed by taps on each side. A gauge was attached for reading the pressures. In this apparatus any pressure up to somewhere over a hundred atmospheres could be obtained.

To charge the apparatus: first, enough solution is introduced to half fill the tube. Then ether is sucked in on the side marked A and the tap closed. By means of a screw coupling B connection is made with a pressure pump and air forced in till the requisite pressure is indicated on the attached gauge when the tap B is closed.

After sufficient time has elapsed for the ether to take up its full complement of water from the solution, the tap A is opened, when the compressed air in the other limb drives the ether out, which is collected and its water content determined.

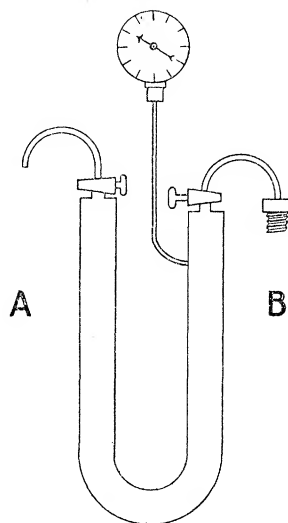
By shaking the tube the length of time required for equilibrium to be reached can be reduced, but care must be taken to keep the ether on the A side.

The strength of the solution with which the experiments described in this paper were carried out was 600 grm. of sugar per litre of solution.

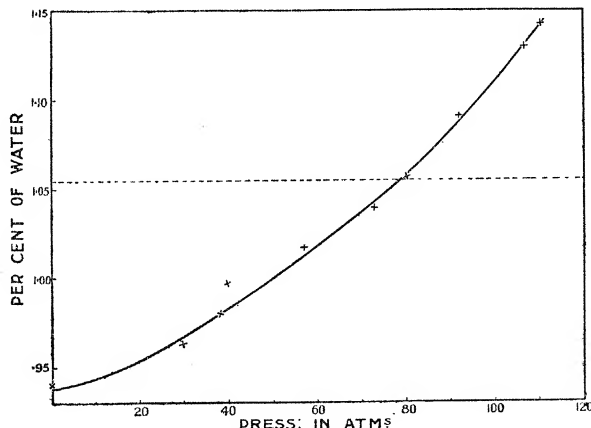
The curve shows the amount of water, in grammes per 100 grm. of the examined ether, found to be taken up from this solution at various pressures ranging from atmospheric up to over 100 atmospheres. It was found in this way that at about 79 atmospheres the amount of water taken up from this strength solution had risen to the amount taken up by ether from water at 1 atmosphere. This amount is indicated on the diagram by the dotted horizontal line. This, according to the above considerations, should be the osmotic pressure of solutions of the particular molecular strength used.

This result may be compared with Lord Berkeley's and Mr. Hartley's*

* 'Phil. Trans.,' A, vol. 206, p. 481.



determinations of osmotic pressure made with a semi-permeable membrane of ferrocyanide of copper on porcelain. They plot a curve from their results obtained with cane sugar, from which we can scale off the value of the osmotic pressure for a solution of 600 grm. per litre. This is about 81 atmospheres, and is, within the limits of error, practically the same as the value given by the ether experiments.



After trying various plans, the one finally adopted for determining the amount of water taken up by the ether was to pass the ether in the form of vapour through calcium chloride drying tubes. The ether was slowly evaporated in a flask placed in warm water. The vapour was led through several drying tubes so as to secure that all the water was absorbed. The escaping ether could be collected and saved when so desired. The drying tubes were kept at 40° C. by placing them in a bath at that temperature. This was sufficiently warm to prevent ether condensing in the tubes, and yet was found not to be too high for substantially absorbing all the water. Before weighing the tubes dry air was run through them, in order to sweep out all ether vapour.

The following table gives the data from which the curve has been plotted. The second column gives the weight of water held by 100 grm. of the ether-water solution in equilibrium with the sugar solution at the corresponding pressure. The corrected weights given in the last column were calculated for convenience of plotting the curve by grouping the observations. This was done for the pressures given in the third column by taking the tangents found from a preliminary curve as giving the rate of change of the weight with pressure, and then taking the mean of the weights so found.

Table I.

Pressure in atmospheres.	Weight held by 100 gm.	Pressure.	Corrected weight.
1	0·935		
1	0·953		
1	0·941		
1	0·938		
1	0·926	1	0·939
30	0·965		
30	0·973		
30	0·953		
30	0·948		
30	0·974	30	0·962
38·1	0·979	38·1	0·979
40	0·964		
40	0·997		
40	0·997	40	0·986
57	1·007		
56·5	1·024		
57·1	1·015		
57·8	1·002		
57·8	1·035	57	1·016
73·1	1·040		
73·5	1·056		
72·8	1·028	73	1·039
80	1·047		
81·5	1·056		
78·9	1·053	80	1·051
93·9	1·103		
92·5	1·093		
92·5	1·089		
92·5	1·098		
91·8	1·077	92	1·090
107·5	1·130	107·5	1·130
110·5	1·143	110·5	1·143

The value assumed for the weight of water taken up by ether at atmospheric pressure when in contact with water is the mean of the following 10 experiments:—

Table II.

1·060	1·032	1·054	1·045	} Mean 1·0545
1·040	1·052	1·087		
1·048	1·063	1·064		

In the determination of osmotic pressure by the semi-permeable membrane method, the difficulty of finding a suitable membrane for most salts becomes very great when high pressures are resorted to, so that it has been found practicable to work with only a limited range of substances. The method here described opens up a wider field, for less exacting conditions have to be complied with in the working material selected, namely, that it should be a substance which takes up the solvent but does not take up the solute,

while, in the case of the material needed for making a semi-permeable membrane, in addition to taking up the solvent but not the solute, it must be either rigid itself or be capable of being mounted on a rigid support.

These determinations were carried out by my assistant, Mr. Burgess, for whose care and accuracy I wish here to acknowledge my thanks.

Mobility of the Positive and Negative Ions in Gases at High Pressures.

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Introduction and Purpose.

The velocity of ions in gases at reduced pressures was first investigated by Rutherford* and by Langevin.† Recently the author and others have carried out similar investigations. The results of these investigations show that for the negative ions in air the product of the mobility and the pressure is constant for pressures ranging from 760 mm. to 200 mm. of mercury, but with further reduction the product increases with the reduction of pressure, this increase becoming very great at low pressures.‡ For the positive ions in air the product of the mobility and pressure is constant for pressures investigated between 760 mm. and 3 mm. of mercury.§ Similar results were obtained for the mobilities of the ions in other gases. The results show that if the ion is an aggregation of molecules, this aggregation becomes, at low pressures, less complex in the case of the negative ion, while in the case of the positive ion it persists down to 3 mm. of mercury.

The purpose of the present research was the study of the mobilities of both kinds of ions in gases at high pressures. The method of investigation is based on the mathematical expression, developed by Prof. Rutherford,|| for the current between two plates, assuming that a very intense ionisation exists near the surface of one of the electrodes.

* Rutherford, E., 'Camb. Phil. Soc. Proc.,' 1898, vol. 9, p. 401.

† Langevin, N. P., 'Ann. de Chim. et de Phys.,' 1903, vol. 28, p. 289.

‡ Kovarik, Alois F., 'Phys. Rev.,' 1910, vol. 30 (4), p. 415.

§ Todd, G. W., 'Camb. Phil. Soc. Proc.,' 1910, vol. 16, p. 21.

|| Rutherford, E., 'Phil. Mag.,' 1901, vol. 2, p. 210.